FINAL TECHNICAL REPORT

RE-EVALUATING THE EARTHQUAKE POTENTIAL AND EARTHQUAKE RECORD OF THE NORTHERN HAYWARD FAULT, SAN PABLO, CALIFORNIA

Recipient:
William Lettis & Associates, Inc.
1777 Botelho Drive, Suite 262
Walnut Creek, CA 94596
Phone (925) 256-6070; Fax (925) 256-6076

Principal Investigators:
John Baldwin[1], Robert W. Givler[1], and Jim Lienkaemper[2]

William Lettis & Associates, Inc.[1],
1777 Botelho Dr., Ste. 262, Walnut Creek, CA 94596
Phone: (925) 256-6070; Fax (925) 256-6076
email: baldwin@lettis.com

U.S. Geological Survey[2]
345 Middlefield Road MS977, Menlo Park, CA 94025
Phone: (650) 329-329-5642; Fax (650)329-5163
email: jlienk@usgs.gov

Program Elements I

Keywords:
Paleoseismology, Surface Deformation, Trench Investigations

U.S. Geological Survey
National Earthquake Hazards Reduction Program
Award No. 07QHGR0080

May 2009

Research supported by U.S. Geological Survey (USGS), Department of Interior, under USGS award number 07QHGR0080. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

AWARD NO. 07QHGR0080

RE-EVALUATING THE EARTHQUAKE POTENTIAL AND EARTHQUAKE RECORD OF THE NORTHERN HAYWARD FAULT, SAN PABLO, CALIFORNIA

Principal Investigators:
John Baldwin[1], Robert W. Givler[1], and Jim Lienkaemper[2]

William Lettis & Associates, Inc.[1],
1777 Botelho Dr., Ste. 262, Walnut Creek, CA 94596
Phone: (925) 256-6070; Fax (925) 256-6076
email: baldwin@lettis.com

U.S. Geological Survey[2]
Western Earthquake Hazards
345 Middlefield Road MS977, Menlo Park, CA 94025
Phone: (650) 329-329-5642; Fax (650)329-5163
email: jlienk@usgs.gov

ABSTRACT

This project was designed to collect paleoseismic event-timing information for the poorly-characterized northern Hayward fault (NHF) at the former El Portal School, in San Pablo, California. The NHF represents the central segment of the 140-km-long Hayward-Rodgers Creek fault (HRCF) system, which according to the latest evaluation by the Working Group on California Earthquake Probabilities (WGCEP) has the highest probability (27%) of the "characterized" faults within the SFBR of producing **M**≥6.7 earthquakes in the next 30 years (2002-2032). Previous paleoseismic investigations at Mira Vista Golf Course, in El Cerrito, by the Hayward Fault Paleoearthquake Group (HPEG) identified stratigraphic evidence for as many as 4 to possibly 7 surface-rupturing earthquakes on the NHF during a 1,630-2,130 year interval; however, because of differences of opinion on the number of events present at the site, the HPEG considered this dataset preliminary and not suitable for "the basis of hazard estimates". Regardless, due to the absence of earthquake timing and recurrence data from elsewhere on the northern Hayward fault, the latest WGCEP results incorporated the HPEG preliminary event chronology and recurrence into the earthquake probability models for the NHF resulting in an 11% probability of a large earthquake (**M**≥6.7) initiating on this fault (2002-2032). In lieu of several recent studies that have resulted in: (1) well constrained event chronology data along the southern Hayward fault at Tyson's Lagoon, (2) relocation of the 1838 earthquake southwest of the SFBR, and (3) re-interpretation of the northern extent of the 1868 rupture on the southern Hayward fault, the seismic hazard posed by the northern Hayward fault is not as well-constrained as previously thought. Thus, this study was aimed at collecting new paleoseismic data to augment the rupture probability models for the HRCF system.

Based on our previous detailed fault hazard evaluation studies performed at the El Portal School site (WLA, 2003), we identified and excavated a 23-m long trench across the main creeping strand of the northern Hayward fault. WLA trench T-3 was shallow (<1.5 meters) on the northeast side of the fault because of shallow groundwater and approximately 4 meters deep on the southwest side of the fault, where groundwater is considerably deeper. The trench exposed a series of thin (0.2 to 0.7 m thick) well-bedded fine-grained Holocene overbank deposits from Rheem and San Pablo Creeks overlain by a middle to late Holocene soil and historic artificial fill.

Unfortunately, no secondary faulting was exposed in this excavation and, therefore, we were unable to identify evidence for past surface-rupturing earthquakes. The primary fault strand, coincident with the creep-related deformation, offsets a massive heavily bioturbated middle to late Holocene soil by 0.5-0.7 meters down to the west. Pervasive bioturbation from large eucalyptus tree roots obscured the stratigraphy near the primary fault trace. This site remains an excellent target for future paleoseismic investigations based on the well-bedded stratigraphy and abundant paleosols underlying the area and the documented secondary deformation in our previous investigation (WLA, 2003). The property is scheduled for demolition in one to three years and may be replaced with a public park.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

1.0 INTRODUCTION

In 2003, the Working Group on California Earthquake Probabilities (WGCEP, 2003) assigned a 27% probability for the occurrence of a large (**M**≥6.7) earthquake on the 140-km-long Hayward-Rodgers Creek fault (HRCF) system, and an 11% probability for a similar size earthquake on the northern Hayward fault that comprises the central segment of this fault system (Figure 1). The 27% probability for the HRCF is among the highest for all faults in the San Francisco Bay Region (SFBR) (WGCEP, 2003). Considering the proximity of the northern Hayward fault to the heavily populated and urbanized East Bay region, the consequences of a large earthquake on the fault are enormous. The lack of significant seismic moment release on the northern segment of the fault within recorded history, suggests that this segment may be prime for a large earthquake. Thus, it is important to regional and local seismic hazard evaluations to understand, as best as possible, the recurrence of large earthquakes on the northern Hayward fault, as well as the HRCF system. The 11% probability estimated by the WGCEP (2003) is based primarily on preliminary paleoseismic data derived by the Hayward Fault Paleoearthquake Group (HPEG, 1999) from the Mira Vista Golf Course site (Mira Vista), creep rate data collected along the fault (Lienkaemper et al., 1991; Lienkaemper and Galehouse, 1997), an assumption that the maximum observed creep rate is comparable to the geologic slip rate, and an assumed amount of coseismic slip. The recurrence interval and thus the time-dependent probability of large earthquakes along the fault is based, therefore, partly an assumed amount of displacement per event, for which there are no well-constrained data for this segment. Currently, there are insufficient data available to reconstruct the latest Holocene earthquake history along the northern Hayward fault, and thus to estimate the recurrence interval for large surface-rupturing earthquakes. Therefore, a better understanding of the timing and recurrence of large earthquakes on the northern Hayward fault is critical for assessing seismic hazard and calculating probabilities of large earthquakes in the San Francisco Bay region. The purpose of this study was to obtain data on the earthquake recurrence of possibly one of the most hazardous seismic sources in northern California, the northern Hayward fault.

Data on the timing of paleoearthquakes on the northern Hayward fault is sparse, poorly constrained, and are based primarily on the findings of an initial study performed at Mira Vista, in El Cerrito, by the HPEG (1999). At Mira Vista, the Hayward Fault Paleoearthquake Group (1999) interpret at least four, and possibly seven or more, surface-faulting earthquakes occurred during a 1,630-2,130 yr interval, with the most recent event (MRE) dated after AD 1640 and prior to AD 1776 (Figure 2). These earthquake timing data yield an average recurrence of about 270 to 710 yr for large earthquakes. The event chronology from Mira Vista is considered likely incomplete by HPEG (1999) and WGCEP (2003), because the trenches intersect only secondary fault traces, and short depositional hiatuses are present that may obscure event occurrence. On the basis of the HPEG (1999) event timing data and above-mentioned shortcomings of the site, the WGCEP (2003) estimated a much lower mean recurrence of 155 yr (95 to 273 years), and acknowledged that the "recurrence history of the Hayward faults remains highly uncertain". Furthermore, the HPEG (1999) note that more trenching is needed along the northern Hayward fault to verify the number and timing of paleoearthquakes interpreted at the Mira Vista site, and that the recurrence interval yielded by this earthquake timing data "should not be used as a basis for computing hazard for the northern Hayward fault." In short, the timing and recurrence of large prehistoric earthquakes on the northern Hayward fault is poorly known. Because recurrence data are critical for estimating the probability of future large earthquakes, and in the absence of coseismic displacement data for the MRE, additional information on the timing of past surface ruptures on the northern Hayward fault is important to developing a better understanding of the seismogenic potential for this fault.

Collecting paleoseismic data is difficult along the northern Hayward fault because much of the fault has been modified by urbanization and extensive development. Thus, there are only a few known viable paleoseismic sites available for paleoseismic investigations. In addition, several long reaches of the fault are covered by large landslide complexes in the heavily urbanized and poorly accessible Berkeley Hills. As a result, there is only handful of locations where evidence of recent faulting is not destroyed by urbanization or readily accessible by a conventional backhoe. This study has built off of WLA's previous research efforts to characterize the Holocene-behavior of the northern Hayward fault (HPEG, 1999; Kelson et al., 2000; Lettis, 2001). For instance, our previous mapping and recent characterization of the northern Hayward fault at El Portal School shows the fault consists of a western main trace and a secondary eastern trace (Figures 2 and 3) (WLA, 2003). As documented by our previous trench, borehole and geophysical investigation at the site (WLA, 2003), the main western fault trace is associated with prominent down to west vertical separation, a groundwater barrier, and development of a tectonically-controlled sag pond with excellent bedded fluvial stratigraphy. In addition, the main western trace is well located based on distressed cultural features at the school (Figures 3 and 4). We have chosen the El Portal School site because of our extensive knowledge of the subsurface geologic conditions, and close working relationship with the West Contra Costa Unified School District (District) and the City of San Pablo.

2.0 TECTONIC SETTING

The Hayward Fault

The Hayward fault includes the southern part of an extensive 275-km-long fault system that comprises the Hayward, Rodgers Creek-Healdsburg, and Maacama faults. The Hayward fault plays a major role in accommodating plate-motion slip in the San Francisco Bay region by accommodating about 25% of the strain associated with the San Andreas fault system. Within this fault system, the Hayward fault lies along the southwestern margin of the East Bay Hills and extends from Warm Springs (Fremont) on the south to San Pablo Bay on the north for a distance of about 87 ± 10 km (Figure 1). Typically, the fault consists of two major sections: the 30 ±15 km long northern, and 55 ± 7.5 km long southern Hayward faults, respectively (WGCEP, 2003). The northern segment of the fault extends from near Berkeley to San Pablo Bay, and is the segment in the direct vicinity of the El Portal School site (Figure 1). Segmentation of the Hayward fault is based, in part, on the occurrence of the 1868 rupture along the southern Hayward fault, as well as the probable timing of past earthquakes on the northern Hayward and Rodgers Creek faults (HPEG, 1999; Lettis, 2001; WGCEP, 2003).

The Hayward fault itself is enigmatic in that it both creeps to an unknown depth along its entire length and is capable of producing large earthquakes, evidenced by the October 21, 1868 M6.8 earthquake (Figures 1). This earthquake was known prior to 1906 as the "great San Francisco earthquake" and after 1906 as the "Hayward's earthquake". The earthquake was accompanied by surface rupture along the Hayward fault zone from near Berkeley to the Warm Springs District of Fremont (Lawson, 1908; Steinbrugge et al., 1987; Yu and Segall, 1996). The northern extent of the rupture is poorly known, however geologic evidence at Mira Vista indicates that the 1868 rupture did not propagate as far north as El Cerrito (HPEG, 1999).

Aseismic slip (fault creep) is occurring along the entire length of the Hayward fault and averages about 5 mm/yr (Lienkaemper et al., 1991; Lienkaemper and Galehouse, 1997; Lienkaemper et al., 2001). Creep rates are highest at the southern end of the fault, where offset cultural features suggest that the fault is creeping at a rate of up to 9.5 mm/yr (Lienkaemper and Borchardt, 1990). A well-documented creeping trace (i.e., main western fault trace) of the Hayward fault passes through the northern fence line of El Portal School, parallel to Castro Street (Figures 2 and 3). Based on numerous surveys, this fence yields a creep rate of about 5 mm/yr (Lienkaemper et al., 1991). Geologic and geodetic slip rates for the fault range between 7 and 10 mm/yr (Prescott et al., 1981; Lienkaemper and Borchardt, 1990; Lienkaemper et al, 1991), with the best estimate for the long-term slip rate at depth being 9 ± 2 mm/yr (WGCEP, 2003). Thus, at El Portal School, the difference between the observed creep rate and long-term slip rate suggest that the fault may be accumulating strain that could be released as a large earthquake.

Recent paleoseismic data collected on the southern Hayward fault at Tyson's Lagoon indicate as many as 11 large surface-fault ruptures within the last approximately 1,800 years, and a recurrence interval of 151 ± 23 years (Lienkaemper and Williams, 2006) (Figure 2). In contrast, geologic data on the timing of late Holocene surface-rupturing earthquakes on the northern Hayward fault is sparse and less well constrained than on the southern fault segment (Figure 2). The paleoseismic research study conducted at Mira Vista Golf Course identified at least four, and possibly as many as seven, surface-fault ruptures within the past approximately 2,100 years, and yielded a minimum recurrence between 270 and 710 years (HPEG, 1999). At this site, the MRE on the northern Hayward fault likely occurred after AD 1640 and prior to 1776. A review of existing earthquake timing data between the two sites (e.g., Tyson's Lagoon and Mira Vista), coupled with recent models on the locking depth and segmentation of the Hayward fault (Simpson et al., 2001; Bürgmann et al., 2000), shows that it is permissible to interpret several nearly continuous ruptures along the entire Hayward fault, as well as possibly separate ruptures constrained to the northern Hayward fault (Figure 2). Currently, the seismic potential of the northern Hayward fault is unclear and requires a re-evaluation of earthquake-timing data and past segmentation boundaries.

Significant uncertainties in characterizing the Hayward fault include the depth that aseismic creep extends into the crust and the role of aseismic creep and contemporary microseismicity in releasing elastic strain along the fault (Simpson et al., 2001; WGCEP, 2003). High-resolution seismicity studies reveal distinct horizontal seismicity lineations along parts of the Hayward fault (Waldhauser and Ellsworth, 1999). The lineations persist over time but with a slow repeat rate suggesting high frictional resistance along the fault is consistent with findings from repeated geodetic surveys across the Hayward fault, indicating that the fault may be locked from about 5 to 13 km in depth (Savage and Lisowski, 1993). More recent modeling of the aseismic behavior of the fault using Global Position Satellite and Interferometric Synthetic Aperture Radar measurements (1992-1997), coupled with contemporary microseismicity, however, suggests that much of the northern Hayward fault may be creeping aseismically to seismogenic depth (approx. 12 to 13 km) (Bürgmann et al, 2000; Schmidt et al., 2005). On the basis of this observation, Bürgmann et al (2000) suggest that the earthquake potential of the northern Hayward fault may be less than previously estimated, and the northern Hayward fault need not produce any large earthquakes. At present, the weight of paleoseismologic evidence supports an interpretation in which the northern Hayward fault experiences surface-rupturing earthquakes (HPEG, 1999) either as an independent source; or alternatively, ruptures coseismically with large events on the southern Hayward fault, or less likely, the Rogers Creek fault. This later scenario is considered unlikely because of the presence of a large (6-km-wide) extensional step-over between the northern Hayward and Rodgers Creek fault beneath San Pablo Bay (Figure 1) (WGCEP, 2003).

3.0 SITE GEOLOGIC CONDITIONS

El Portal School

Review and interpretation of historical aerial photography (circa 1939) and a circa 1952 topographic map indicate that prior to school construction, the northern and central part of the site consisted of gentle northwest-sloping undeveloped grasslands, whereas the southern part of the site included a prominent northwest-trending "pressure-ridge" (Figure 3). Present-day channelized Rheem Creek, that lies northeast of the site, formerly consisted of small meanders and bends, as well as a northwest-trending linear channel that aligned subparallel with the eastern margin of the "pressure ridge" (Figure 2). Present-day Rheem Creek is channelized, lies directly east of the school site, and occupies a similar location to that of the past. Topographic alterations to the site include placement of artificial fill within the topographic lows (swales and basins) associated with the western trace of the Hayward fault, and grading of the "pressure-ridge" by as much as one meter in the southern part of the site.

Evidence of aseismic creep is well documented in the direct site vicinity and at the site (California Geological Survey, 1982; Herzog Associates, 1990; Lienkaemper et al., 1991; WLA, 1999; WLA, 2003) as noted by offset fences, en echelon fractures developed in asphalt, displaced building walls, curbs and sidewalks (Figures 3 and 4). A chain-linked fence located at the northern part of the site, parallel to Castro Street, provides a creep rate of about 5 mm/yr for the main western trace (Lienkaemper et al., 1991). A 2-m-wide zone of left-stepping, en echelon fractures intersect Castro Street directly northwest of the offset fence and extend northwest into the Contra Costa Community College (CCC) parking lot. Further northwest on the CCC campus, ornamental bricks and curbs are right-laterally offset, with some rotated in a clockwise direction, thus further delineating the northwest projection of the main creeping trace (e.g., western fault trace) of the Hayward fault.

Evidence of creep-related deformation along the eastern trace is less conspicuous compared to the western trace. At or near the southern boundary of El Portal School, the absence of distinct evidence for distressed cultural features suggests that the eastern fault trace dies out. This model is consistent with our trench findings (trench WLA T-2) that exposed only a minor fault zone along the suspected eastern trace, and the absence of distressed school structures unequivocally formed by aseismic creep (Figure 4). Thus, the observed 5 mm/yr creep rate at the site represents as much as 50% of the long-term slip rate of 9 ± 2 mm/yr for the fault (Lienkaemper and Borchardt, 1996; WGCEP, 2003), suggesting that the remainder of the slip represents accumulated strain that could be released as a large earthquake along the northern Hayward fault, or accommodated by a through-going rupture associated with the southern Hayward fault.

The primary fault zone at El Portal School site coincides with the western fault trace and a local structural depression filled with laterally continuous, well-bedded 0.2 to 0.3 ft. thick fluvial strata derived from paleo-San Pablo and Rheem Creeks (WLA, 2003) (Figure 6). Separating several of the fluvial deposits are thin, well developed to incipient paleosols suggesting periodic stages of landscape stability. The structural depression (sag pond) is bounded on the east by the western trace of the Hayward fault and numerous east-dipping subvertical faults along the western boundary to the maximum depth explored of 13.5 feet (Figure 4). Based on the presence of argillic horizons, clay films, pedogenic structure, and detailed pedogenic characterization, WLA (2003) estimated middle to late Holocene age for the sag pond deposits present in the southern part of the site.

The sag pond is bordered on the east by the primary creeping strand of the Hayward fault (N30°W to N35°W) and numerous near-vertical secondary faults along both margins that exhibit normal separation and range in strike from N10°W to N8°E. Shears in the western part of the basin accommodate down-to-the-east vertical separation, whereas shears in the eastern part of the basin accommodate down-to-the-west vertical separation (Figure 4). Collectively, across the main fault trace and sag pond there is as much as 1 m of vertical separation, consistent with subsidence of the structural depression. Several episodes of surface-fault rupture are evident by the upward termination of shears at different stratigraphic horizons. Lastly, the main western trace is delineated by the presence of a 3-to 5-m-wide zone of abundant near-surface fracturing (creep-related), abrupt westward tilting of stratigraphy, and the presence of a groundwater barrier that impounds water east of the fault zone.

4.0 TRENCHING INVESTIGATION

4.1 Approach

On October 22, 2008 a 23-m long trench, named WLA T-3, was excavated across the western trace of the northern Hayward fault at the El Portal School site (Figure 3). The trench trended obliquely across the fault in a narrow unpaved strip adjacent to the offset chain-link fence and the former school parking lot (Figure 5). The trench was shallow (<1.5 meters) on the northeast side of the fault because of shallow groundwater and its close proximity to Rheem Creek, and approximately 4 meters deep on the southwest side of the fault, where groundwater is considerably deeper west of the fault. We attempted to extend the deep section of the trench to the northeast to expose a deeper portion of stratigraphy at the fault zone (see note G, Plate 1) and, by doing so, perforated the natural groundwater barrier produced by the fault. To prevent the trench from filling with ground water, the extended section of the trench was quickly back filled and compacted with the backhoe bucket to maintain the groundwater barrier and stratigraphy at the fault zone was not available for review and interpretation. This led to less than desirable conditions to assess paleoseismic stratigraphy.

WLA trench T-3 exposed bedded late Holocene alluvium derived from paleo-San Pablo and Rheem Creeks. The trench was cleaned, strung with several horizontal level lines with 1-meter spacing, flagged, and photographed. During excavation, we removed a series of large decayed eucalyptus stumps from the excavation. The root systems associated with the stumps extended to as much as 3 meters deep and often obscured the stratigraphic and structural relationships in the trench wall. No secondary faults were identified within trench T-3, and thus the trench was logged at approximately one-inch equals a meter (~1:40-scale; Plate 1). Detailed lithologic descriptions of trench strata are shown on Plate 1 and discussed below.

We presented the preliminary results of the trench exposures during a field trip of the northern Hayward fault for the East Bay Hazards Conference (Baldwin and Lienkaemper, 2008). We also led tours of the trench and discussed our results with engineers and officials with the City of San Pablo and with a geology class with Contra Costa Community College. All participants were very interested in the results of our investigation, and the earthquake hazards associated with the northern Hayward fault.

4.2 Stratigraphy

The trench exposed a series of well-bedded fine-grained Holocene overbank deposits from Rheem and San Pablo Creeks overlain by a middle to late Holocene soil and artificial fill. These units are further subdivided and described in detail on Plate 1. For the purpose of discussing the results of this investigation, a reference to the general units is sufficient and includes Holocene overbank deposits, middle to late Holocene soils, and artificial fill.

The Holocene over bank deposits exposed in WLA trench T-3 consist of a series of seven well-expressed alluvial deposits (Plate1). These units are between 0.2- to 0.7-m thick and represent overbank deposits from Rheem and San Pablo Creeks. Periods of relative stability are marked by thin, generally less than 1 cm thick, incipient paleosols marked by a faint black color and manganese staining. For example, units 21 and 22 are fine-grained sand and clay deposits (10- to 30-cm-thick) capped by thin incipient paleosols and a thicker buried A-horizon (Unit 23). The overbank deposits of Units 32 and 33 are very similar to the lower units discussed and also contain a series of thin incipient laterally discontinuous paleosols developed within and capping these units (see Plate 1 and Note D). Unit 33 is buried by a paleosol (Unit

40) that consists of black silty clay and calcium carbonate filaments. Unit 40 contains medium to fine blocky and prismatic pedogenic structure and traces of carbonate filaments. Bedding attitudes within the western portion of trench T-3 indicate the stratigraphy generally strikes approximately northwest and has a gentle eastward dip (4-6ºE) toward Rheem Creek.

The upper part of WLA trench T-3, consists of a 0.2- to 1.0-meter-thick middle to late Holocene soil that caps the overbank sequence described above (Plate 1). Unit 41 consists of black silty clay with weak to moderately developed soil structure, including both blocky and prismatic structure, carbonate filaments and carbonate coatings. Clay films on soil peds were not identified. The soil is massive with no relict stratigraphy preserved. Based on characteristics of these soils and our previous study (WLA, 2003) are middle to late Holocene in age. This unit is laterally continuous across the trench and appears to thin and thicken across the fault zone (may be due to grading of original site surface).

Artificial fill (Unit 50) consisting of a basal sand and gravel layer, overlain by both road base material and silty sand, overlies the former well-developed soil of Unit 41 throughout the trench exposure (Plate 1). Southwest of station 11-m, the fine sand to sandy silt that overlies the basal gravel has a platy to block pedogenic structure with a weak A horizon marking the top of the unit in places. No shears were identified in the fill.

4.3 Faulting

No distinct fault strands, fissures, or offsets were identified in the bedded alluvium and buried paleosols of WLA trench T-3. After careful inspection, cleaning, and flagging of both trench walls, it was concluded that no discrete shears or faults were present in the existing trench exposure. As noted above attempts were made to expose the inferred fault zone, however, shallow groundwater conditions and high-flowing springs prevented unsafe working conditions and eliminated the ability to interpret the bedded stratigraphy present beneath the upper massive soils.

From the limited trench exposure, we interpret the abrupt thickening of Unit 41 by as mush as 0.5-0.7-m and the basal contact of the unit vertically displaced down to the west as much as X m as fault related (Plate 1). It is likely that some of the apparent thickening of Unit 41 across the fault zone is related in part to the nearly horizontal grading of the site prior to placement of the artificial fill (Unit 50). The location of the abrupt down-warping of Unit 41 coincides with a deflected chain-link fence and curbs directly north of the trench (Figure 3 and 7). Several poorly expressed fractures with diffuse boundaries are present between stations 9 and 10 m, however, these thin fractures (i.e., possibly creep-related) are filled with soil and do not offset stratigraphic units. The fractures may be older root-filled bioturbated zones, however, the truncation of the fractures at the base of Unit 41 suggests that they may be tectonic-related. Unfortunately, a large tree stump that spanned both trench walls was encountered at the inferred fault location and obscured much of the upper part of the inferred fault zone and shallow soil stratigraphy surrounding the fault (Figure 7; Plate 1). The buried tree stump, coupled with the shallow groundwater conditions on the northeast side of the fault, significantly limited the opportunity to expose and identify discrete fault offsets in the primary fault zone of the creeping strand of the northern Hayward fault. No shears or kinematic indicators were identified in the trench exposure.

Only minor folding was identified near mapped location of the western trace of the Hayward fault. From stations 11-m to 14-m, the base of Unit 31 and 33 appear to be gently folded within the fault zone by 2º to 3º. The presence of a large krotovina and root casts within Units 31 and 32 obscured the increase of tilting of several thin incipient soils developed within these units (See Note E Plate 1). These gentle warps are likely the result of fault-related deformation similar to trench exposures T-1 and T-2 of WLA (2003). Lastly, the zone of folding is within a meter or two of where the groundwater barrier was perforated and is interpreted to represent near-fault deformation. Unlike previous trench T-1 of WLA (2003), no secondary faults or the presence of a sag pond were exposed in WLA trench T-3.

5.0 CONCLUSIONS

Exposures of the well-bedded near surface stratigraphy in WLA trench T-3 revealed no subsurface structure that could be used readily for obtaining paleoearthquake timing data. The tilted stratigraphy at the fault zone is similar to the fault-related fold exposed in previous WLA trench T-1 (2003) located further to the south (Figure 3). This folding and the inferred fault location are coincident with creep-related deformation directly north and south of the trench. Unlike previous WLA trenches T-1 and T-2 (WLA, 2003), no secondary faults were identified with the warping in the WLA trench T-3 exposure. The absence of secondary faulting could be related to:

- A subtle change in fault geometry that concentrated fault surface rupture on the main creeping fault strand
- Abundant roots and tree stumps that obscured offset stratigraphy near the primary fault strand;
- The inability to excavate the trench to greater depths east of the fault or at the fault zone;
- The presence of the pressure ridge in the southern part of the site may influence secondary faulting west of the structural topographic high.

Future extensive trenching and dewatering techniques may provide the necessary exposures to observe the fault zone and fault-related structures for paleoseismic assessment. This study did identify that the area has excellent stratigraphy and, combined with the results of previous studies (WLA, 2003), remains an excellent site for further investigating the paleoseismic history of the northern Hayward fault. Future trenching investigations should consider a dewatering program to lower the groundwater table on the northeast side of the fault to allow exposure of deeper stratigraphy near the main fault strand. We believe with a more focused trenching effort and a larger number of trench locations available after site demolition, this site potentially could contain valuable paleoearthquake timing information on the northern Hayward fault.

6.0 REFERENCES

Baldwin, J.N and Lienkaemper, J. 2008, Holocene Surface Deformation along the Northern Hayward Fault, San Pablo to Oakland, CA, Third Conference on Earthquake Hazards in the Eastern San Francisco ay Area Science, Hazard, Engineering and Risk, California State University East Bay, Hayward, California, 174 p.

Bürgmann, R., Schmidt, D., Nadeau, R.M., d'Alessio, M., Fielding, E., Manaker, D., McEvilly, T.V., and Murray, M.H., 2000, Earthquake potential along the northern Hayward fault, California, Science, 289, p. 1178-1182.

California Geological Survey, 1982, Special Study Zones, Richmond 7.5-minute quadrangle (scale 1:24,000).

Darwin Myers Associates, 1984, Fault Hazard Investigation Sojourner Truth Presbyterian Church, 2621 Shane Drive, Richmond, California; unpublished geotechnical consulting report dated December 3, 1984.

Dibblee, T.W., Jr., 1980, Preliminary Geologic map of the Richmond Quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open-File Report 80-1100 (scale 1:24,000). Earth Science Associates (ESA), 1976, Geologic report as required by Alquist-Priolo Special Studies Zone for Whitecliff Knolls, Richmond, California: Unpublished consulting report for Whitecliff Homes dated 6/1976.

Engeo Corporated (ENGEO), 1978, Alquist-Priolo Investigation of Arlington Car Wash Addition, Richmond, California: Unpublished consulting report for Mobile Corporation dated June 22, 1978.

Hayward fault Paleoearthquake Group, 1999, Timing of Paleoearthquakes on the Northern Hayward fault – Preliminary Evidence in El Cerrito, California, U.S. Geological Survey Open-File Report 99-318.

Herzog Associates, 1990, Geotechnical investigation, El Portal School, Richmond, California: Unpublished consulting report for Interactive Resources dated 4/26/1990.

Helley, E.J. and Noller, J.S., 1992, Geologic map of the Richmond 7.5 minute quadrangle, Contra Costs and Alameda Counties, California: U.S.G.S. Open File Report OF-92, map scale 1:24,000.

Kelson, K.I., Koehler, R.D., Baldwin, J.N., Witter, R.C., Lettis, W.R., and Sojourner, A.C., 2000, Paleoearthquake investigations of the northern Hayward fault, San Francisco Bay Region, California: Final Technical Report, U.S. Geological Survey, Menlo Park, California, NEHRP Award 1434-HQ-98-GR-00044.

Lawson, A.C., 1908, The earthquake of 1868; in A.C. Lawson (ed.), the California earthquake of April 18, 1906: Report of the State Earthquake Investigation Commission (vol. 1): Carnegie Institute of Washington Publication 87, p. 434-448.

Lettis, W.R., 2001, Late Holocene Behavior And Seismogenic Potential Of The Hayward-Rodgers Creek Fault System In The San Francisco Bay Area, California: in H. Ferriz (ed.), Engineering Geology Practice in Northern California, Association of Engineering Geologists, Special Publication 12, Bulletin 210, p. 167-177.

Lienkaemper, J.J., and Borchardt, G., 1990, Holocene slip rate, historic creep rate, and the potential for large earthquakes on the Hayward fault, California: EOS, v 72, no. 43, p. 1645.

Lienkaemper, J.J., Borchardt, G., and Lisowski, M., 1991, Historic creep rate and potential for seismic slip along the Hayward fault, California: Journal of Geophysical Research, v. 96, no. B11, p. 18,261-18,283.

Lienkaemper, J.J., and Borchardt, G., 1996, Holocene slip rate of the Hayward fault at Union City, California: Journal of Geophysical Research, v.101, no. B3, p. 6099-6108.

Lienkaemper, J.J., and Galehouse, J.S., 1997, Revised long-term creep rates on the Hayward fault, Alameda and Contra Costa Counties, California, U.S. Geological Survey, Open-File Report 97-690, 18 p.

Lienkaemper, J.J., and Williams, P.L., 1998, New evidence in north Oakland of minor ground rupture on the Hayward fault and major rupturing in prehistoric earthquakes, Geophysical Research Letters, v. 26, p. 1949-1952.

Lienkaemper, J.J., Galehouse, J.S., and Simpson, R.W., 2001, Long-term monitoring of creep rate along the Hayward fault and evidence for a lasting creep response to 1989 Loma Prieta earthquake, Geophysical Research Letters, vol. 28, no. 11, p. 2265-2268.

Lienkaemper, J.J., and Williams, P., 2006, Paleoseismic investigations on southern Hayward fault at Tyson's Lagoon (Tule Pond), Fremont, California, in 3rd Annual Northern California Earthquake Hazards Workshop, January 18-19, 2006, U.S.G.S. Earthquake Hazards Program.

Nilsen, Tor, H. 1973, Preliminary photointerpretation map of landslide and other surficial deposits of the Concord 15-minute quadrangle, and the Oakland West, Richmond, and part of the San Quentin 7.5-minute quadrangles, Contra Costa and Alameda Counties, California, Misc. Field Studies Map MF-493; scale 1:62,500.

Prescott, W.H., Lisowski, M., and Savage, J.C., 1981, Geodetic measurement of crustal deformation on the San Andreas, Hayward, and Calaveras faults near San Francisco, California. Journal of Geophysical Research, v. 86, no. B11, p. 10,853-10,869.

Savage, J.C., and Lisowski, M., 1993, Inferred depth of creep on the Hayward fault, central California, Journal of Geophysical Research, v. 98, p. 787-793.

Schmidt, D.A., Bürgmann, R. Nadeau, R.M., and d'Alesio, M., 2005, Distribution of aseismic slip rate on the Hayward fault inferred from seismic and geodetic, Journal of Geophysical Research, vol., 110, B08406.

Simpson. R.W., Lienkaemper, J.J., and Galehouse, J.S., 2001, Variations in creep rate along the Hayward fault, California, interpreted as changes in depth of creep, Geophysical Research Letters, vol. 28, no. 11, p. 2269-2272.

Steinbrugge, K.V., Bennett, J.H., Lagonio, H.J., Davis, J.F., Borchardt, G., and Toppozadda, T.R., 1987, Earthquake planning scenario for a magnitude 7.5 earthquake on the Hayward fault in the San Francisco Bay area: California Division of Mines and Geology Special Publication 78, 229 pp.

Yu, E., and Segall, P., 1996, Slip in the 1868 Hayward earthquake from the analysis of historical triangulation data: Journal of Geophysics Research, v. 101, p. 101-116, 118.

Waldhauser, F. and Ellsworth, W.L., 1999, Preliminary results from high-resolution seismicity analysis on the Hayward fault: Letter to Working Group 1999 reporting on work in progress, 7 p.

William Lettis & Associates, Inc., 1999, Surface-fault rupture hazard evaluation, proposed Child Day Care Center, Contra Costa College, West Campus, San Pablo, California: Unpublished geologic consulting report dated June 7, 1999.

William Lettis & Associates, Inc., 2001, Surface Rupture Hazard Evaluation for Proposed Renovations at Mira Vista Golf and Country Club: Final Report, Mira Vista Golf and Country Club, El Cerrito, California.

William Lettis & Associates, Inc., 2003, Seismic Hazard Evaluation, El Portal Elementary School, West Contra Costa Unified School District, 2600 Moraga Road, San Pablo, California: unpublished consultant report dated February 19, 2003.

Williams, P.L., 1993, Geologic record of southern Hayward fault earthquakes: California Division of Mines and Geology Special Publication, v. 113, p. 171-179.

Working Group on California Earthquake Probabilities (WGCEP), 2003, Earthquake probabilities in the San Francisco Bay region: 2002-2031: U.S. Geological Survey Open-File Report 03-214.

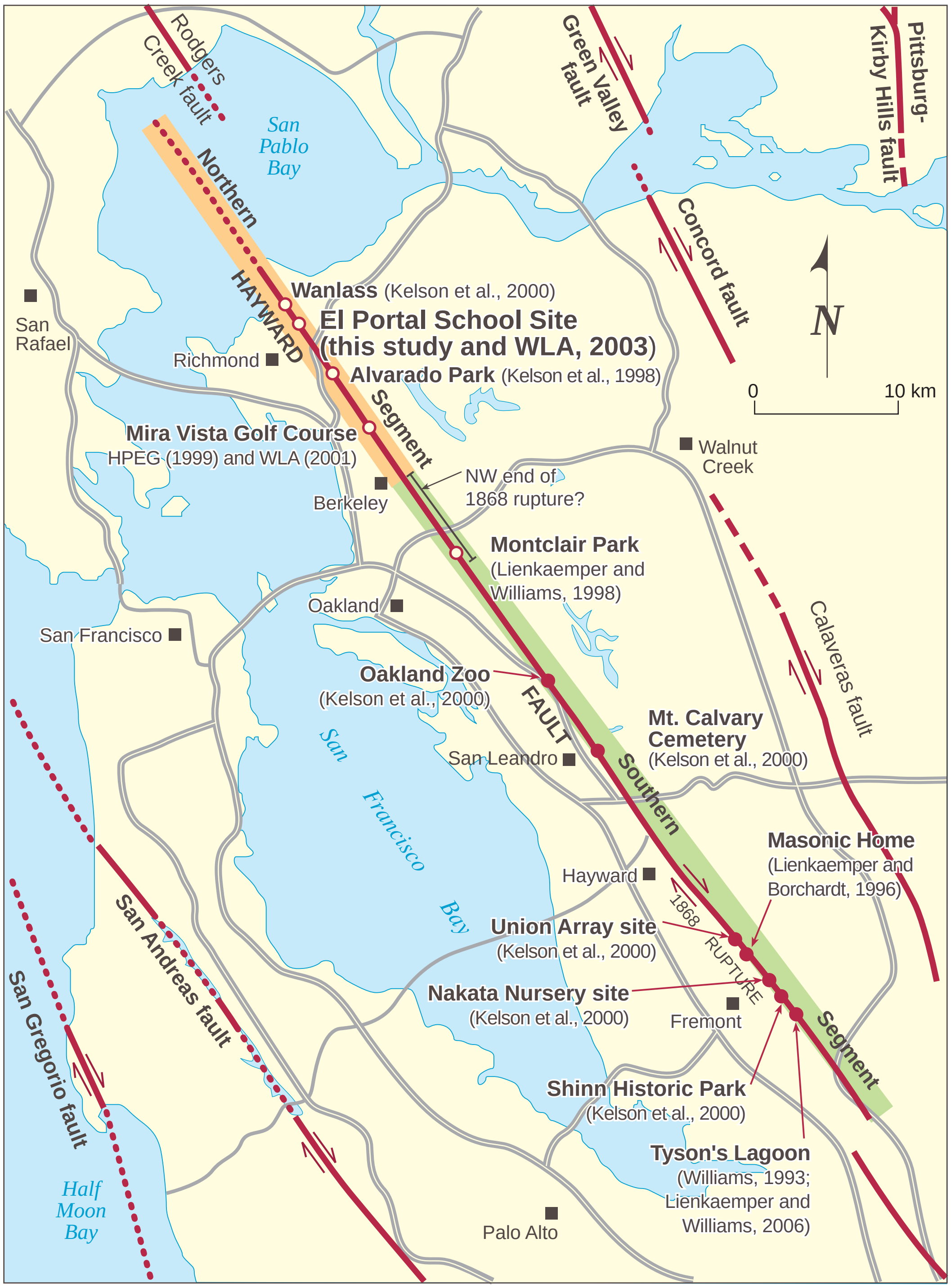


Figure 1. Regional fault map of the Hayward fault showing the 1868 rupture (green) and the previous research sites on the northern and southern Hayward fault segments. Segment boundaries based on WGCEP (2003).

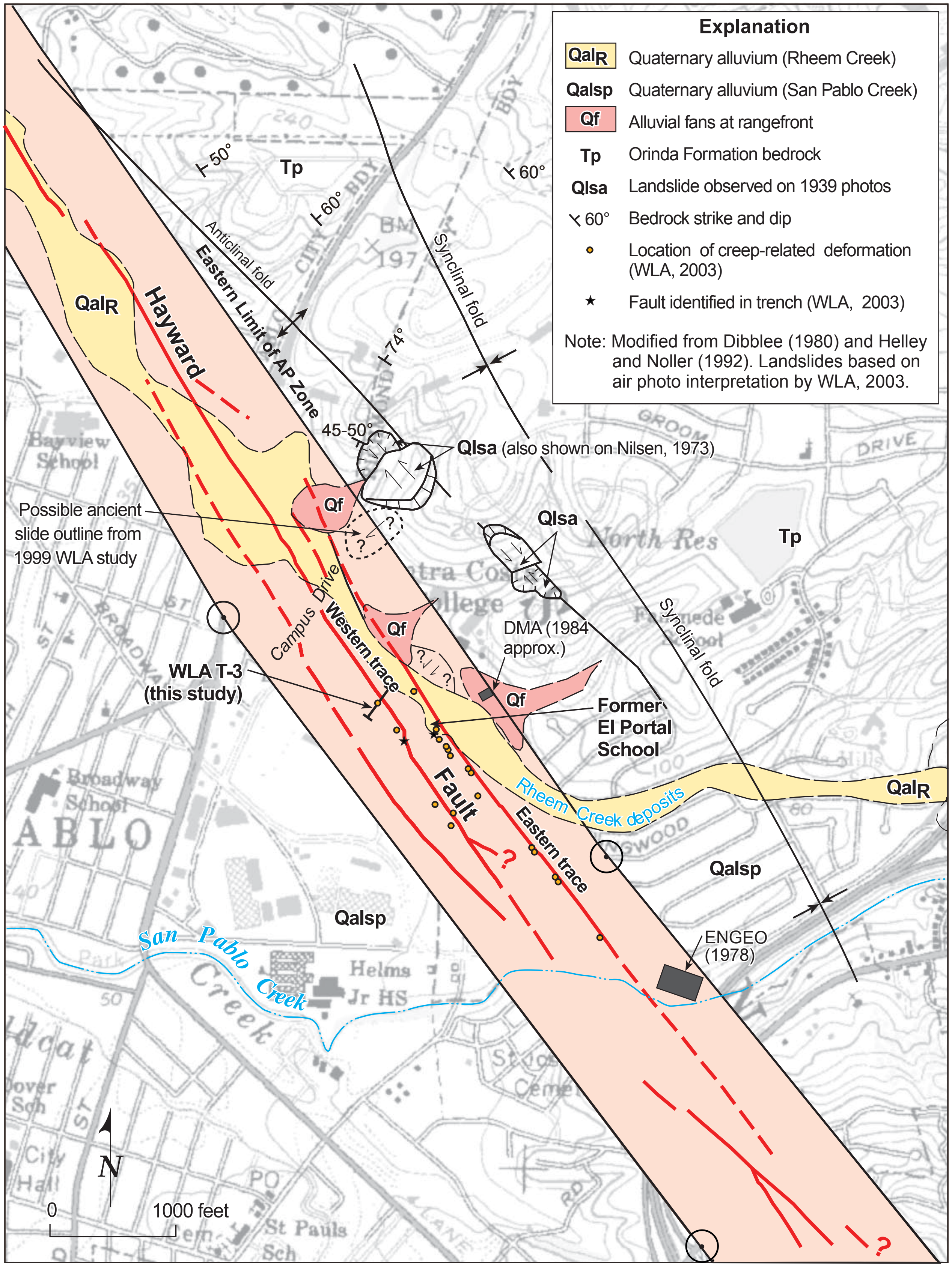


Figure 2. Regional geologic map modified from Dibblee (1980) and Helley and Noller (1992). Fault traces are from 1982 A-P map. Previous investigation locations are approximate.

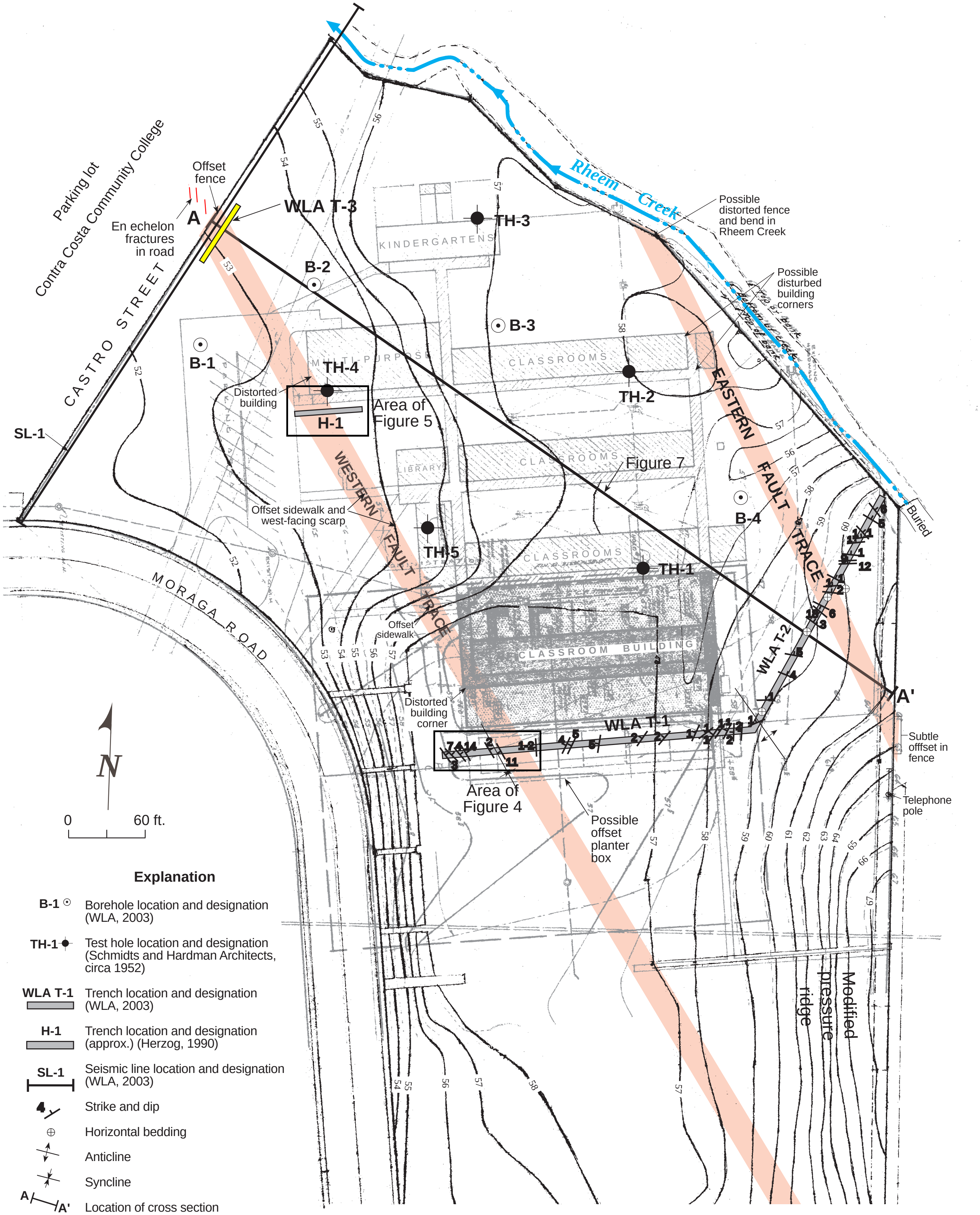


Figure 3. Site map showing locations of proposed and previous trenches, boreholes, and seismic lines at El Portal School, San Pablo, California. Hayward fault locations are based on recent trenching data, observed locations of aseismic creep, and represent the location of prominent traces. Note light gray topographic lines are close to existing site topography, whereas black lines represent former topography (circa 1952) in feet.

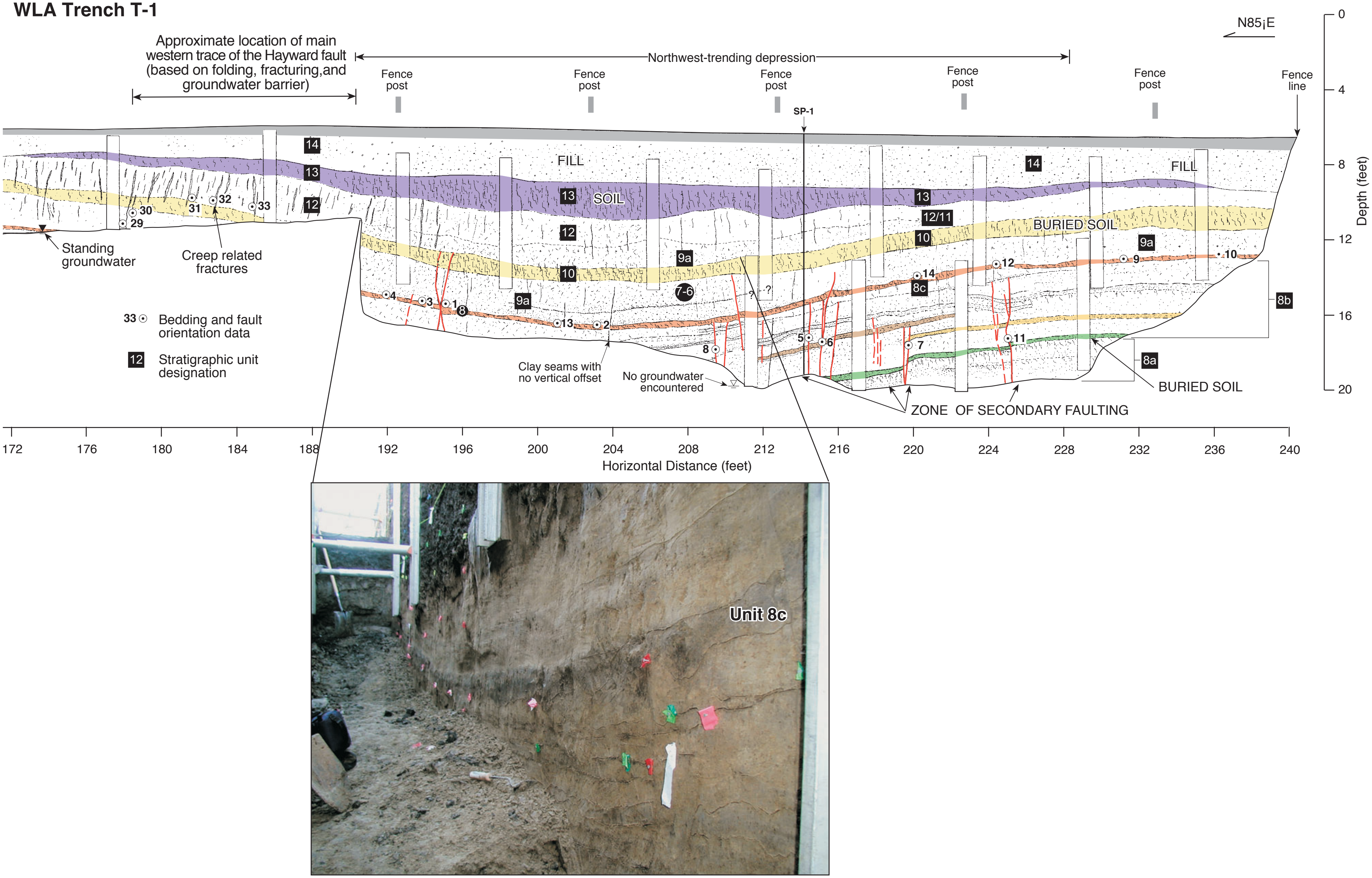


Figure 4. Upper figure depicts WLA trench T-1 (WLA, 2003) from the El Portal School. It shows bedded and faulted stratigraphy of main western trace and northwest-trending depression with secondary faults. Note the presence of creep-related deformation in WLA trench T-1 aligns with groundwater barrier of the main western fault trace. Photograph shows warped and faulted sag pond deposits (Unit 8) encountered in the southwest end of WLA trench T-1 (photograph of southern wall looking eastward).

Figure 5. Field photograph of WLA Trench T-3 illustrating the location of creep-related offset of the chain link fence.

Figure 6. Field photograph of WLA Trench T-3 between Stations 12 m and 23 m illustrating the well-bedded stratigraphy exposed in the trench.

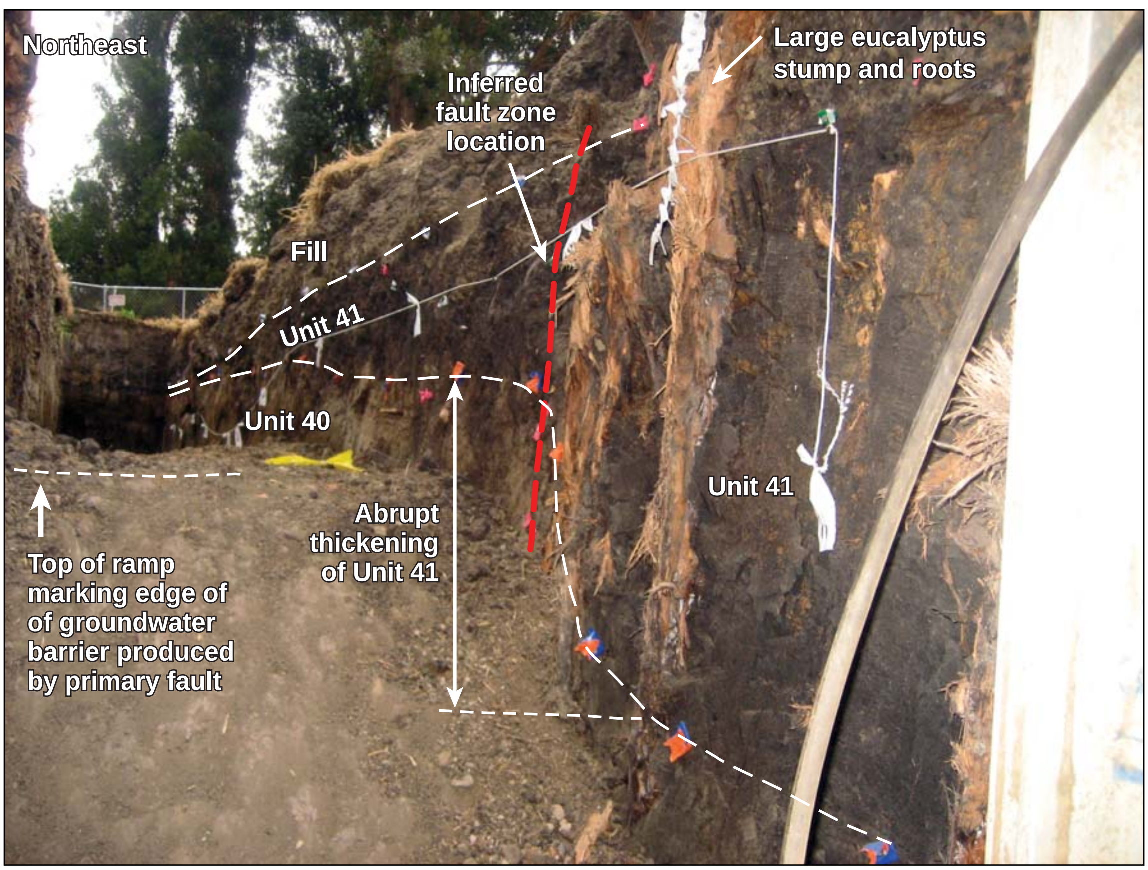
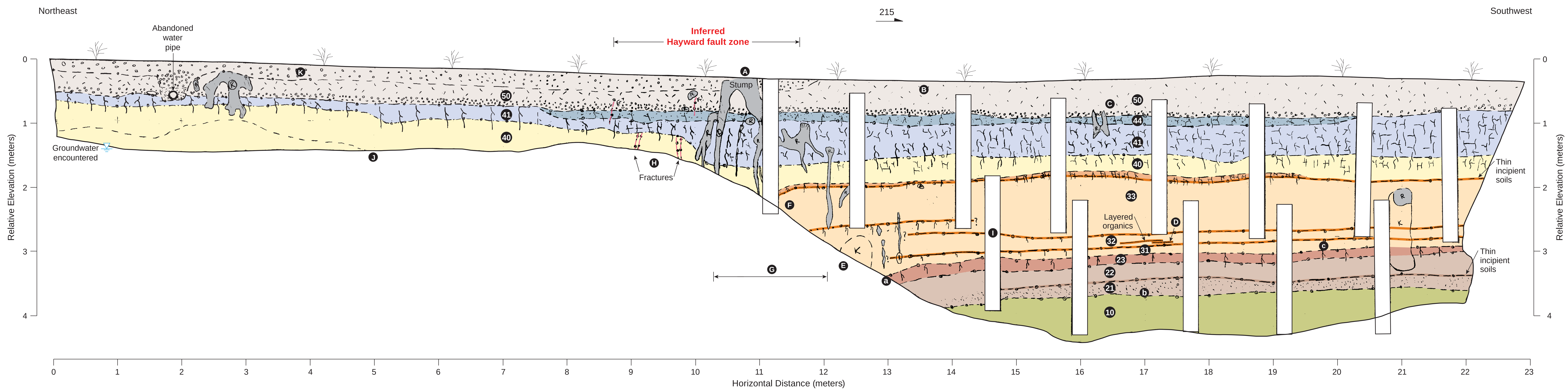


Figure 7. Field photograph of the abrupt thickening of Unit 41 across the primary creeping strand of the northern Hayward fault.



Explanation

Symbols

- Fracture, dashed where approximate
- Contact, solid where well located, dashed where approximate
- Krotovina
- Root
- Soil development and structure

Unit Descriptions

10 CLAY, silty; brown to dark grayish brown (10YR 4/2), moist, moderate plasticity, massive with faint laminae, rootlets, no soil structure, relict bioturbation, lower contact not exposed. [OVERBANK and ALLUVIAL FAN]

21 SAND, very fine to silty fine SAND with trace pebbles, grayish brown (10YR 5/2), moist, low to moderate plasticity, one inch diameter pebbles at base of unit, coarsening upwards, faint black laminations several millimeters thick, moderate fine rootlets, mottled with iron oxide, no soil structure; thin dark grayish brown (10YR 4/2) incipient soil horizon mapped at top of unit, marked by increased organics and is laterally continuous; Unit 21 has a clear planar lower boundary. [OVERBANK ALLUVIUM]

22 CLAY, silty to silty SAND with clay present at base of unit, brown (10YR 4/2), moist low plasticity, blackish massive mottling with faint laminations, erosional lower boundary is clear and planar. [OVERBANK ALLUVIUM]

23 SILT, clayey with trace sand, dark grayish brown (10YR 4/2), moist, massive, mottled, with fine black specks (charcoal or manganese), rootlets present, up to 15 centimeters thick, well-developed A-horizon developed in unit, diffuse lower contact that is slightly wavy. [BURIED A-HORIZON]

Unit Descriptions (continued)

31 SILT, sandy with clay, grayish brown (10YR 5/2), moist, mottled, roots up to 5 millimeters in diameter with oxidation halos, capped by thin incipient soil, abrupt to sharp lower boundary. [OVERBANK ALLUVIUM].

32 SILT, clayey to silty CLAY, very dark grayish brown (10YR 3/2) to dark grayish brown (10YR 4/2), moist, porous, multiple laminae and thin incipient A-horizons within four distinct packages (see Note 4), each package approximately one centimeter thick, lower boundary is sharp to gradational. [OVERBANK ALLUVIUM]

33 SILT, sandy, grayish brown (10YR 5/2), moist, mottled, 10 to 15% sand, large infilled krotovina with dark organic materials, rootlets present, weak dark soil horizon caps unit, soil marked by weakly developed medium to fine blocky to prismatic structure with trace $CaCO_3$ filaments, soil discontinuous in southwest portion of trench, lower boundary is clear and planar. [OVERBANK ALLUVIUM]

40 CLAY, silty, black (10YR 2/1), moist, root casts and roots to 2.5 inches, mottled from black to brown, similar to Unit 33, but with more soil structure, $CaCO_3$ filaments, medium to fine prismatic soil structure, lower boundary is clear. [BURIED A-HORIZON]

Unit Descriptions (continued)

41 CLAY, silty, black (10YR 2/1), with trace fine pebbles (< 10%), moist to dry, abundant rootlets, medium to fine weak prismatic structure, upper portion is blocky and medium to coarse, $CaCO_3$ filaments and coatings on pebbles (<10% pebbles in unit), lower boundary is clear and wavy. [A-HORIZON]

44 SAND, fine to medium, with gravel, yellowish brown (10YR 5/6), angular to subrounded gravel with mixed lithologies, wavy clear lower boundary contact. [OVERBANK ALLUVIUM]

50 SAND and GRAVEL, black (10YR 2/1) and brown (10YR 4/2), 30% gravel (subrounded pebbles) at base of unit; sand and gravel overlain by very fine SAND to sandy SILT, dark gray (10YR 4/1) to gray (10YR 5/1), up to 8 centimeters thick with very abrupt contact with basal gravel, platy to blocky ped structure, root rich, in places a weak A-horizon marks the top of the unit, up to 60 centimeters thick, lower boundary is wavy clear lower contact. [FILL]

Notes

- **A** Large stump obscured and destroyed inferred fault zone stratigraphy on both walls.
- **B** Mixed artificial fill and A-horizon
- **C** Old soil filled stump.
- **D** Multiple thin incipient soils. Four distinct soils approximately one centimeter thick
- **E** Incipient soils obscured by roots and large krotovina.
- **F** Subtle warping of Unit 33
- **G** Trench extended to tree root at depth where water was encountered; more prominent drag folding at fault but not possible to log because of rapid free-flowing groundwater.
- **H** Fractures 1 to 3 centimeters thick. Filled with black soil
- **I** Very subtle swale but no secondary faulting
- **J** Oxidation boundary between brown (above) and olive-brown (below) clayey silt
- **K** Road material

Attitudes

- **a** N50ºW, 5 to 10ºE
- **b** N60ºW, 6ºE
- **c** N45ºW, 4ºE

U.S.G.S. N.E.H.R.P. EL PORTAL SCHOOL SITE
SAN PABLO, CA

Trench T-3
South Wall

WLA William Lettis & Associates, Inc. Plate 1

Modified 03.09.09

1873 El Portal